Argonne NATIONAL LABORATORY

Study of Color Transparency in Exclusive Vector Meson Electroproduction off Nuclei

Hall C Summer Workshop

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Kawtar Hafidi

COLLABORATION

J. Arrington , D. F. Geesaman, R. J. Holt,
B. Mustapha, D. H. Potterveld, P. E. Reimer
Argonne National Laboratory

Graduate Students:

Lamiaa El Fassi (ANL)
Lorenzo Zana (UNH)

Spokespersons:

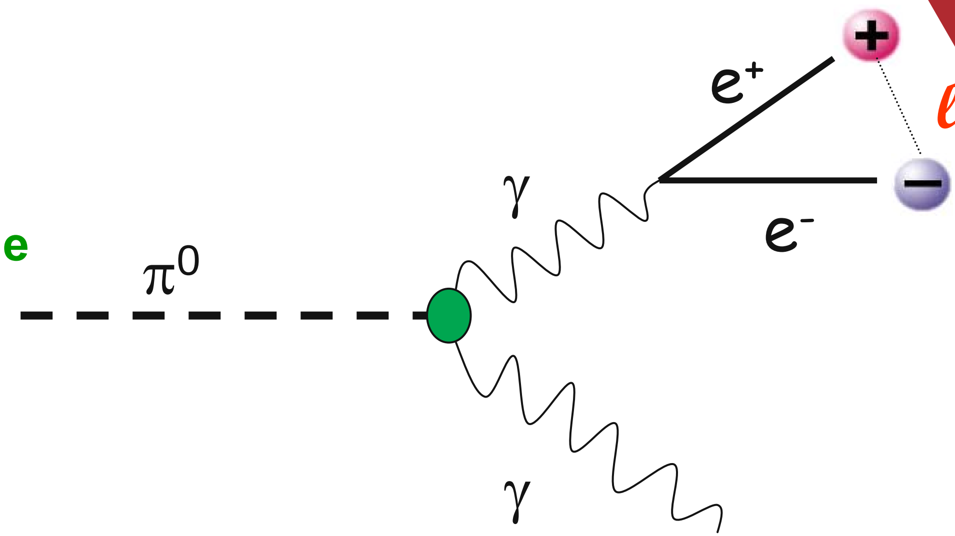
K. Hafidi and B. Mustapha (ANL)
M. Holtrop (UNH)

And CLAS Collaboration

Overview

- Physics Motivation
- EG2 Experiment
- Preliminary Results
- Summary and Outlook

Origin of CT



- Discovery by Perkins (1955) of the (Dalitz) decays in emulsion of π^0 (~ 200 GeV) produced in cosmic rays $\pi^0 \rightarrow e^+ e^- \gamma$

- The ionization produced by the pair was small near the decay point, increasing with distance from vertex

- This surprising observation was quickly interpreted by Chudakov (1955) in the framework of QED: A pair of oppositely charged particles interacts in the medium

with a dipole cross-section

$\Rightarrow$ this cross-section ($\sigma \cong \ell^2$) vanishes near the creation point

In early 80's, Brodsky and Mueller applied the notion of transparency to QCD and to color charge

Color Transparency is a spectacular **prediction of QCD**:

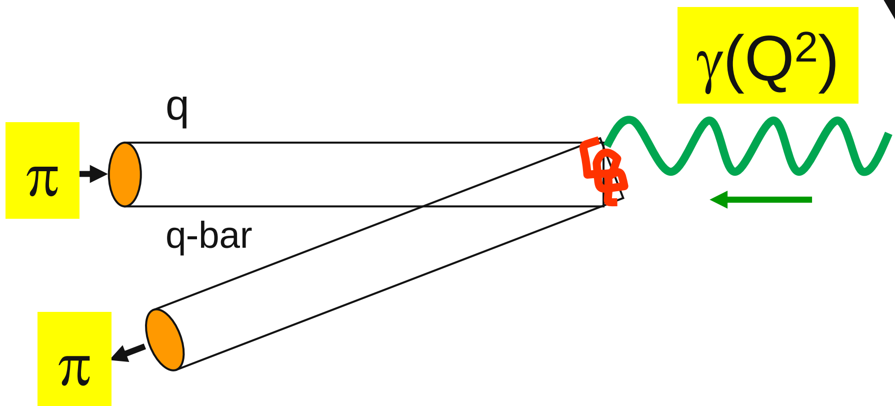
Under the right conditions, the nuclear matter will allow the transmission of hadrons with **reduced attenuation**. Such a phenomenon is totally **unexpected in a hadronic picture of strongly interacting matter**, but **straightforward in quark gluon basis**, this is one of the features which makes it so interesting.

Right Conditions ⇒ Selection of Point Like Configurations (PLC) via hard exclusive processes

Hard: high momentum transfer

Exclusive: completely determined initial and final states.

Elastic processes are special cases



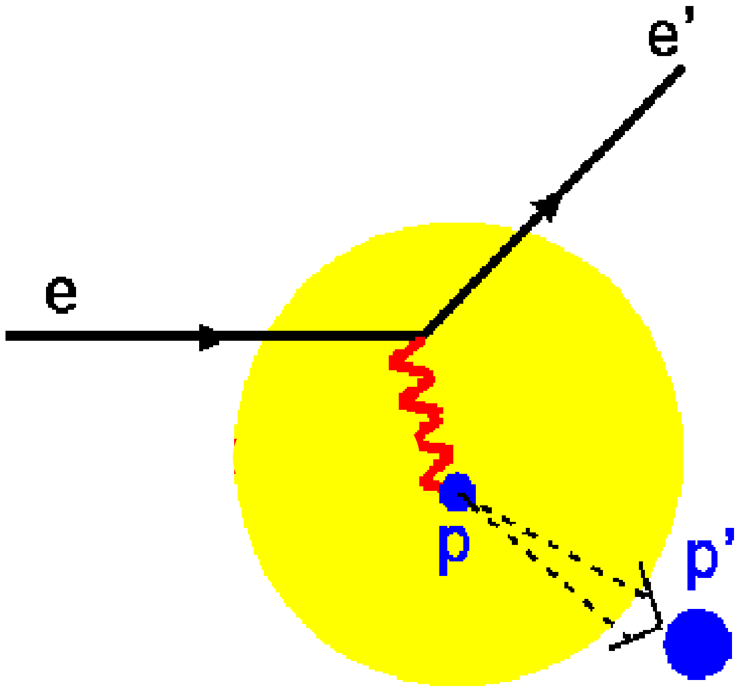
Electromagnetic form factor of the pion in the Breit frame

- **Unless the struck quark shares the momentum transfer with the other quark, the pion fragments and the reaction is inelastic**

- **As Q increases, the exchange of the gluon has to be fast.**
  Causality (no interaction is faster than speed of light)
  ⇒ the quark's pair has to be localized within a transverse size of 1/Q

Color screening: PLC experiences reduced interaction in the nucleus

In QCD the color field of a color neutral object vanishes as the size of the object is reduced



Because

The field of individual quarks and gluon cancel each other as the size is reduced by analogy to QED

Therefore

The interaction cross-section has a dipole form

$\sigma \cong \ell^2$

ℓ is the separation between the constituents

Hadronic point of view of CT & PLC formation time

- **The point like aspect is seen as a consequence of coherent superposition of large number of resonances with specific weights**

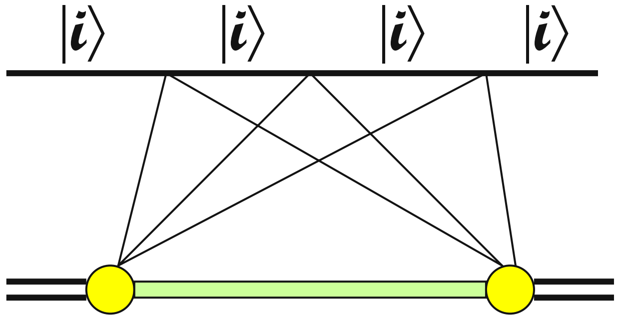
- **CT is understood as a coherence of the scattering of these resonances inside the nucleus**

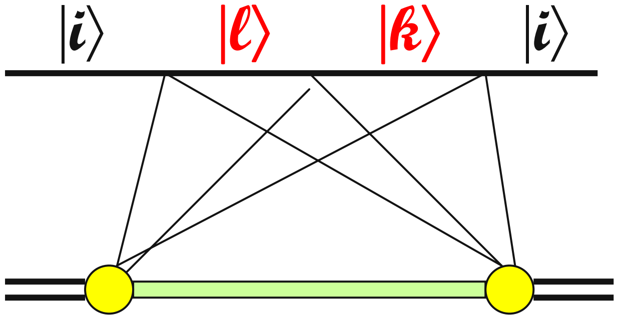
- **The formation of PLC is a function of the typical excitation energy of the system**

$$\frac{1}{\tau_f} \cong \sqrt{E_h^2 + M^{*2}} - \sqrt{E_h^2 + M^2}$$

Assuming $\nu \cong E_h \cong p$

$$\boxed{\tau_f \cong \frac{2\nu}{M^{*2} - M^2}}$$





What can we learn from studying CT ?

$|\text{Meson}\rangle = Z_0\, |q\ q\text{-bar}\rangle + Z_1\, |q\ q\text{-bar}\ \ q\ q\text{-bar}\rangle +$ …..

- PLC is by definition a product of short distances: it can only come from valence component (higher order are reduced by a factor α_s)
- CT mechanism selects the simplest component of the hadron wave-fun By analogy to lattice QCD, we are in the "quenched approximation"
- All the physics programs build around CT idea would allow us not only to access special configurations of the hadron wave-function but also t study how this configuration dresses with time to form the asymptotic wave-function of the hadron with all its complexity
- **We are here in the heart of the dynamics of confinement !**

The nucleus, a unique laboratory of quark dynamics

- **Characteristic proper time scale is $\tau_0 \sim$ 1 fm**

  τ_0 is the time needed by a quark to travel distances typical of the confined systems

- Taking into account Lorentz dilation, the proper time scales in

  the Lab frame become $\tau = (E/M)\, \tau_0 \sim$ few fm

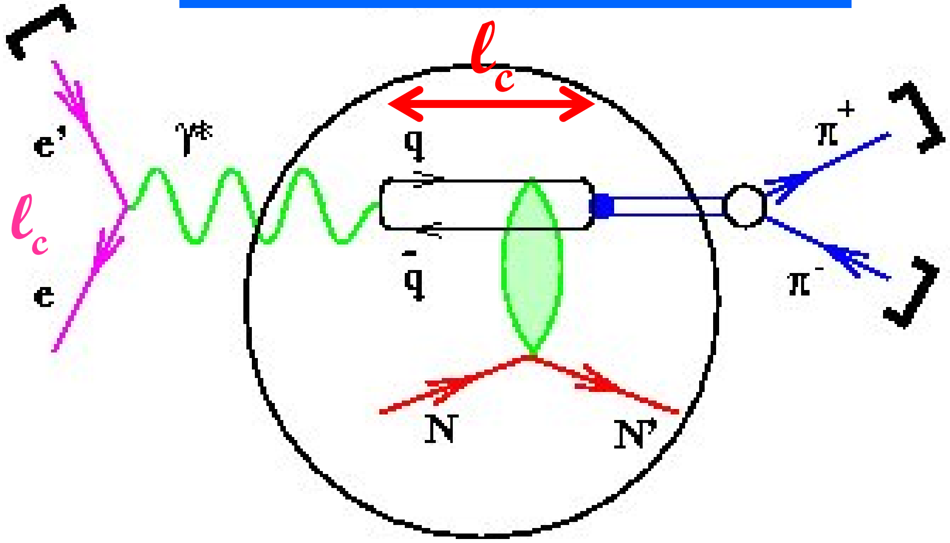
- The only medium available for these scales is the nucleus !

- The nucleus is playing the role of the bubble chamber !

ρ^0 electroproduction on nuclei

Detected particles are :
scattered electron and the π^+ and π^- from ρ^0 decay

$e + N \rightarrow e' + N + \rho^0$

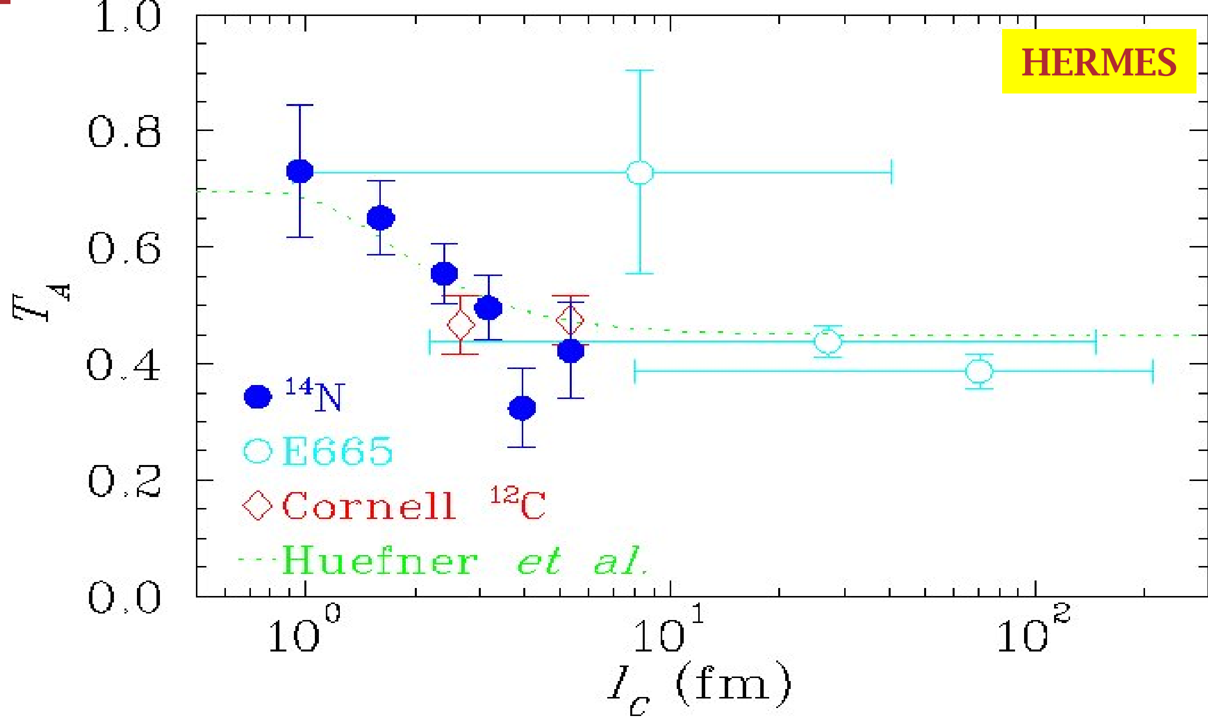


Finite propagation distance ℓ_c (lifetime) of the (q,q-bar) virtual state

$$\ell_c = 2\nu/(M^2 + Q^2)$$

M is the mass of the vector meson
ν is the energy transferred by the electron

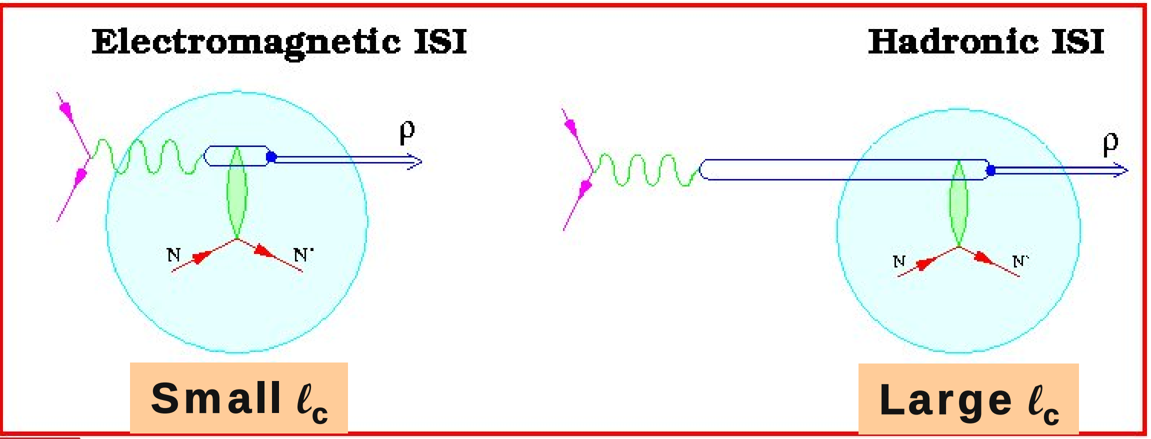
What Could mimic CT signal ?



Coherence Length

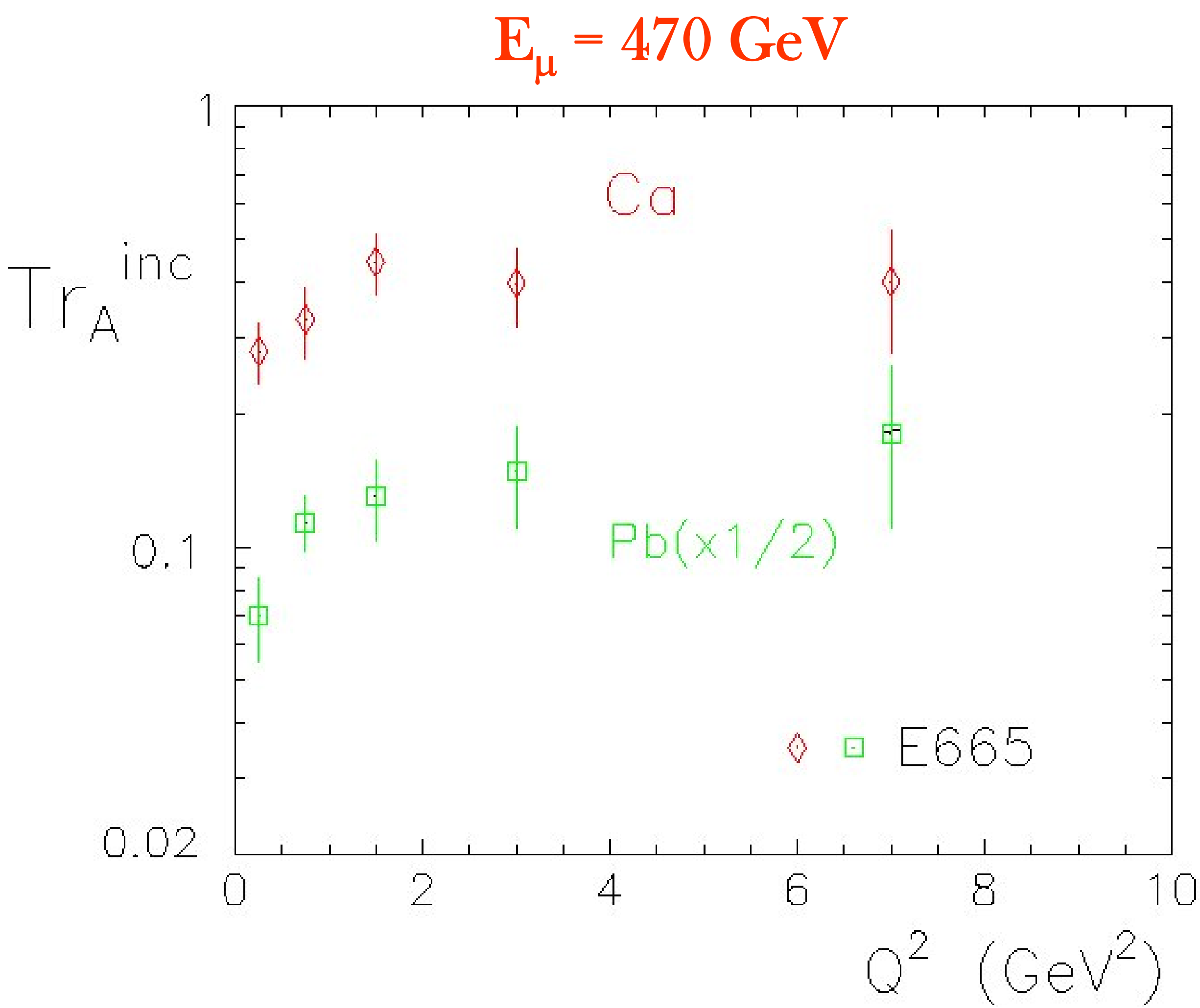
$\ell_c = 2\nu/(M_v^2 + Q^2)$

Coherence length effect (CL): Q^2 increases $\Rightarrow T_A$ increases



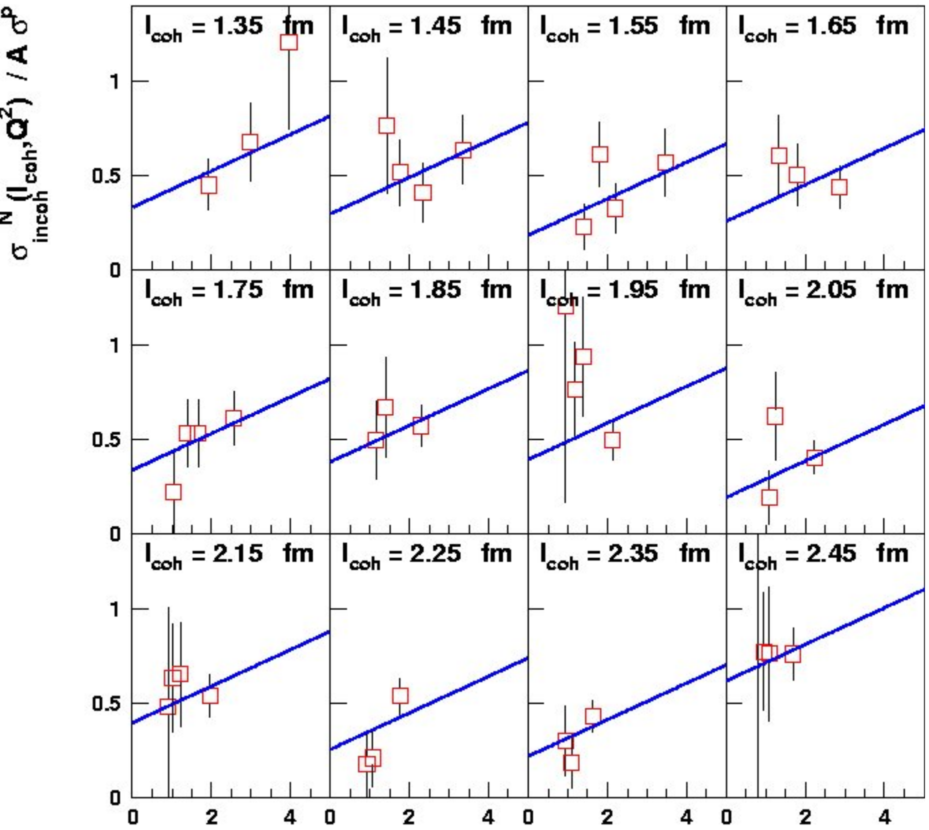
- Coherence Length effect can mimic CT signal
- To be safe, one should keep ℓ_c fixed and measures the Q^2 dependence of T_A

FNAL E665 experiment



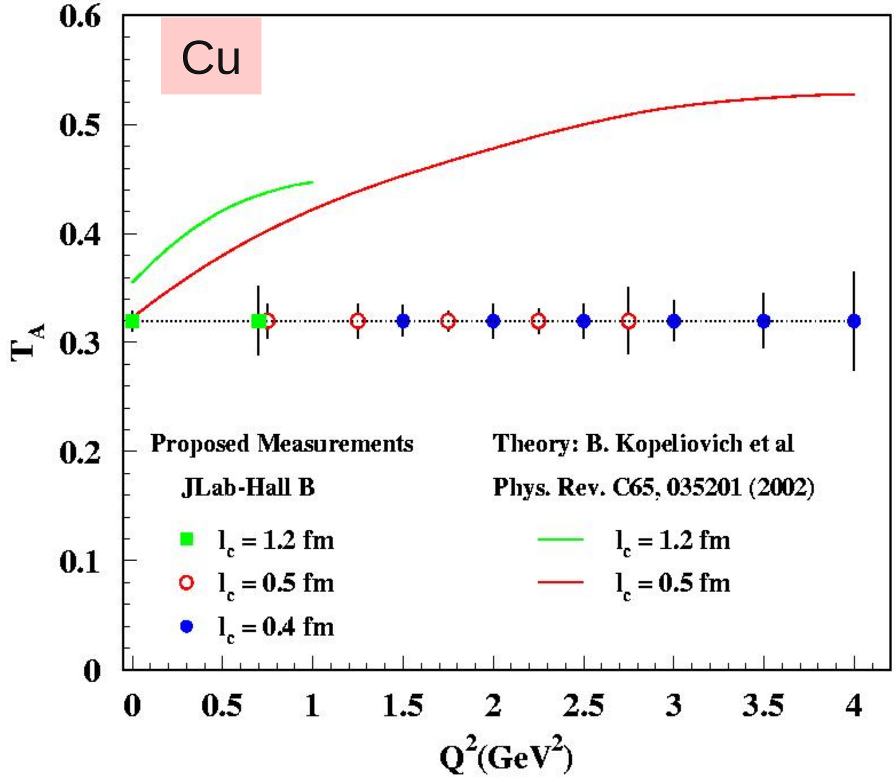
Adams et al. PRL74 (1995) 1525

ρ^0 electroproduction at fixed CL



Phys. Rev. Lett. 90 (2003) 052501

Data taken in 2004

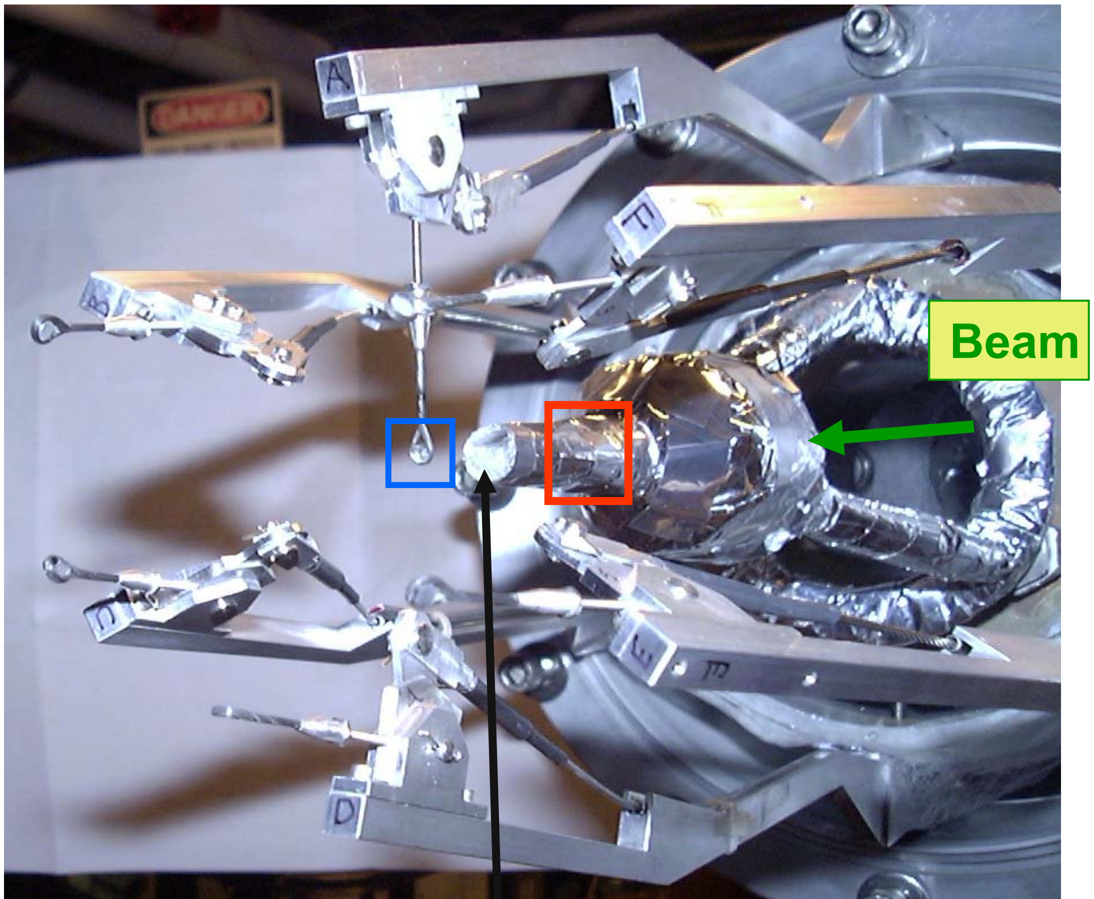


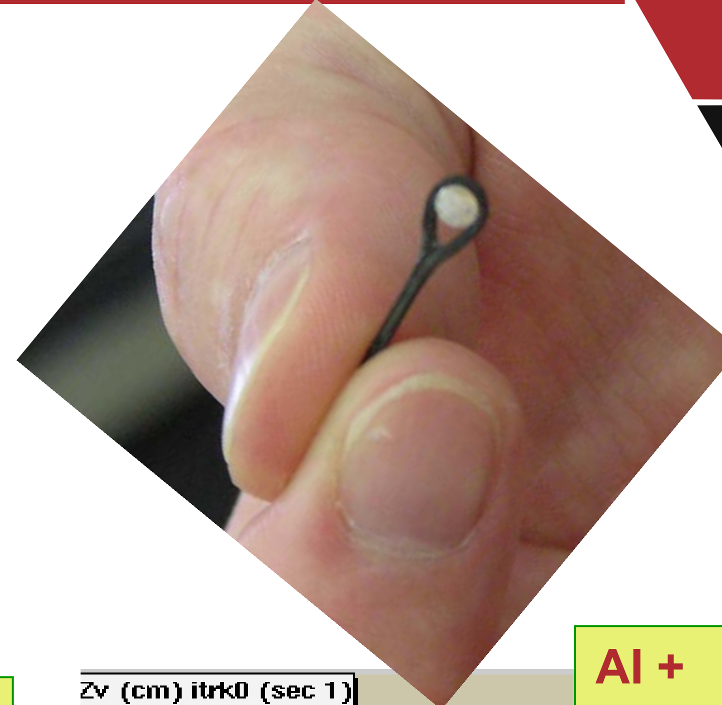
HERMES Nitrogen data : $T_A = P_0 + P_2 Q^2$

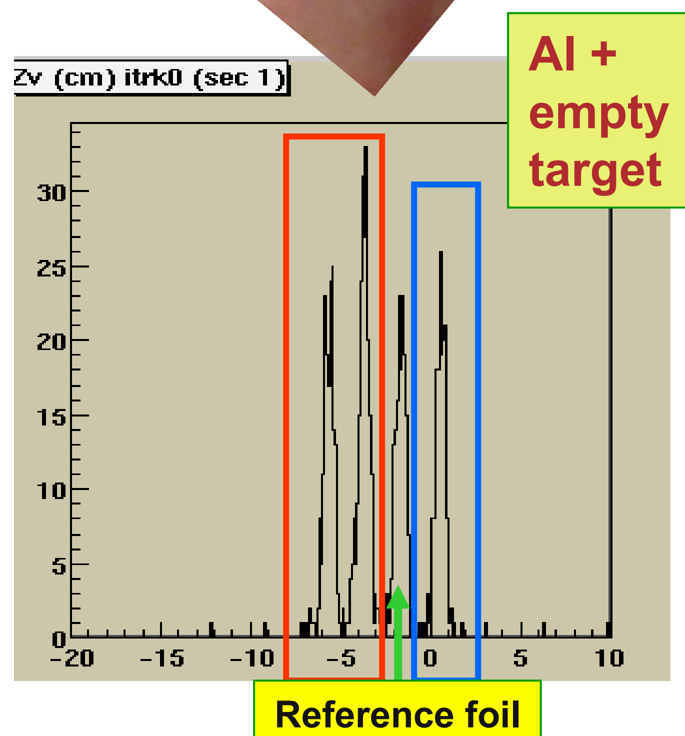
P2 = $(0.097 \pm 0.048_{stat} \pm 0.008_{syst})$ GeV^{-2}

JLab-CLAS E02-110 projected uncertainties

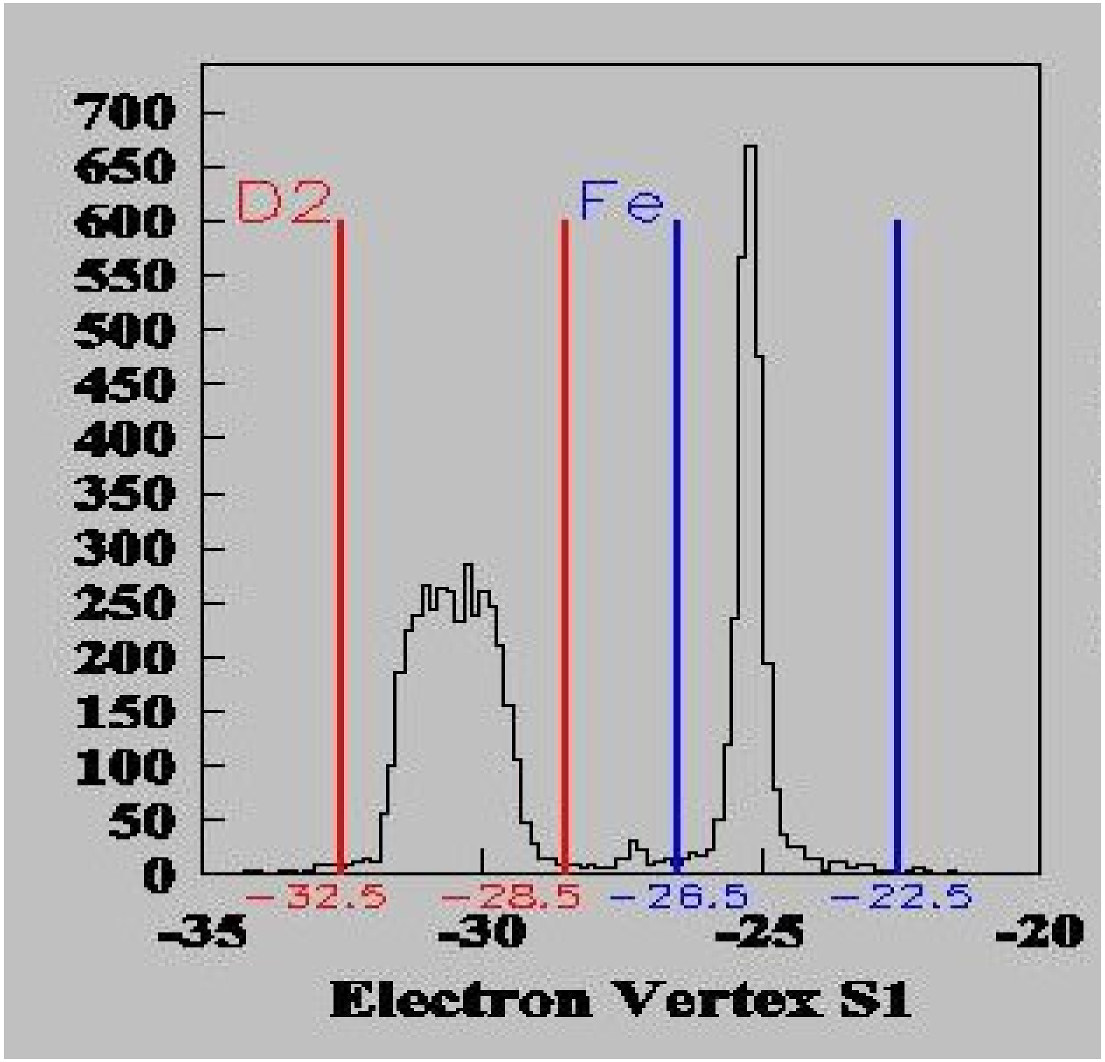
Targets







Vertex cut



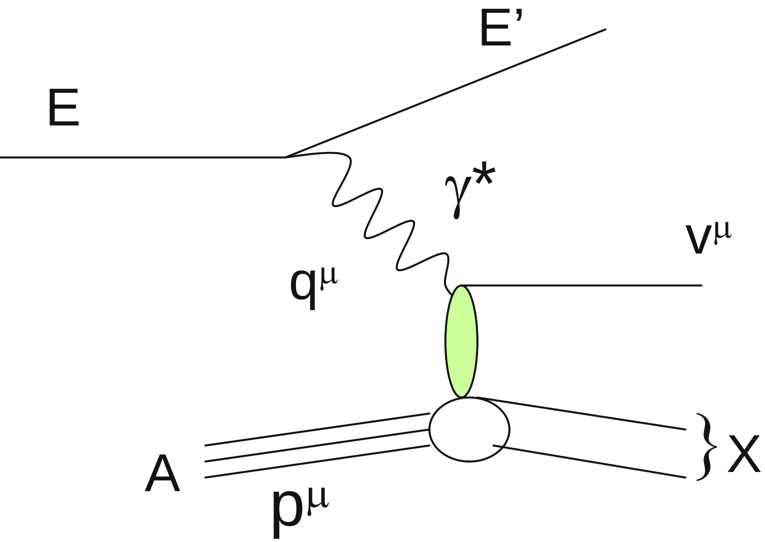
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
D2
Fe
-32.5
-28.5
-26.5
-22.5
-35
-30
-25
-20
Electron Vertex S1

$e + Fe \rightarrow e' + \rho^0 + X$

$\rho^0 \rightarrow \pi^+\pi^-$

$e + D \rightarrow e' + \rho^0 + X$

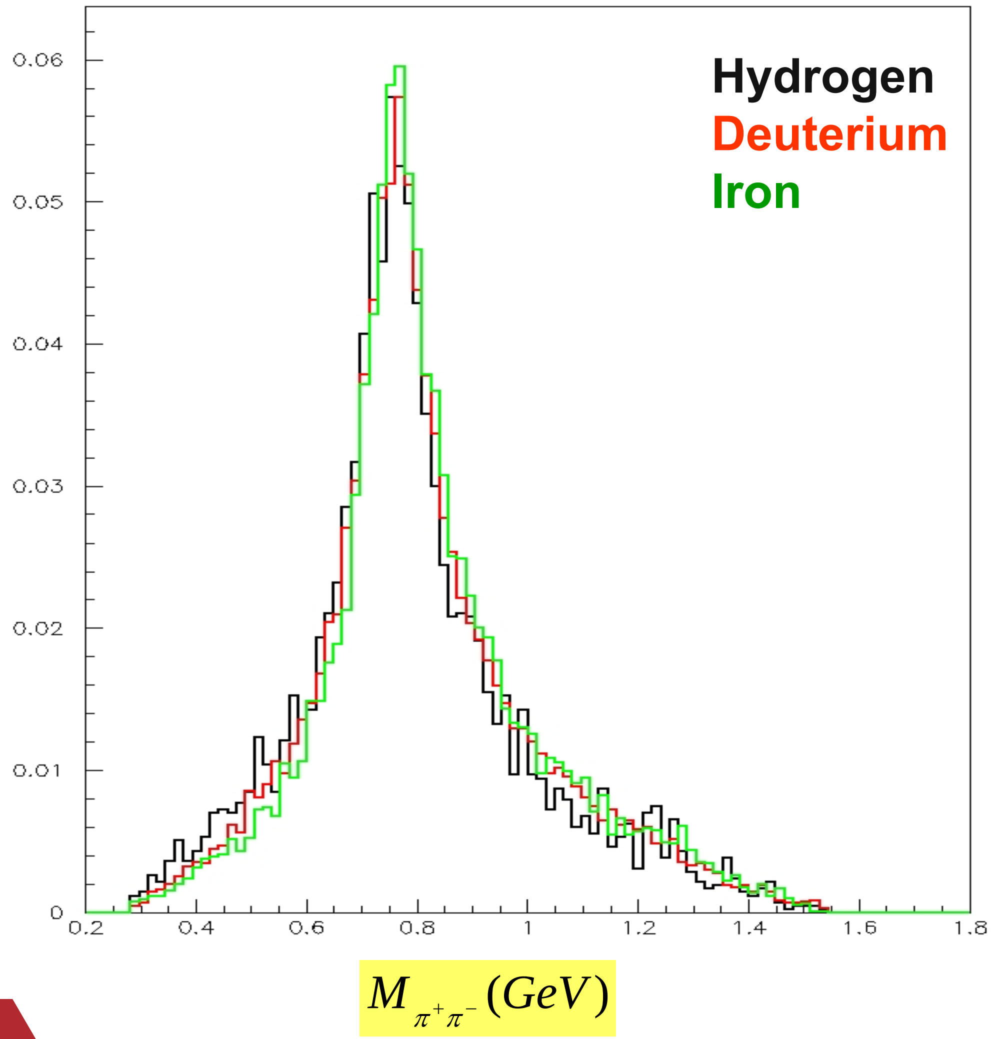
$\rho^0 \rightarrow \pi^+\pi^-$



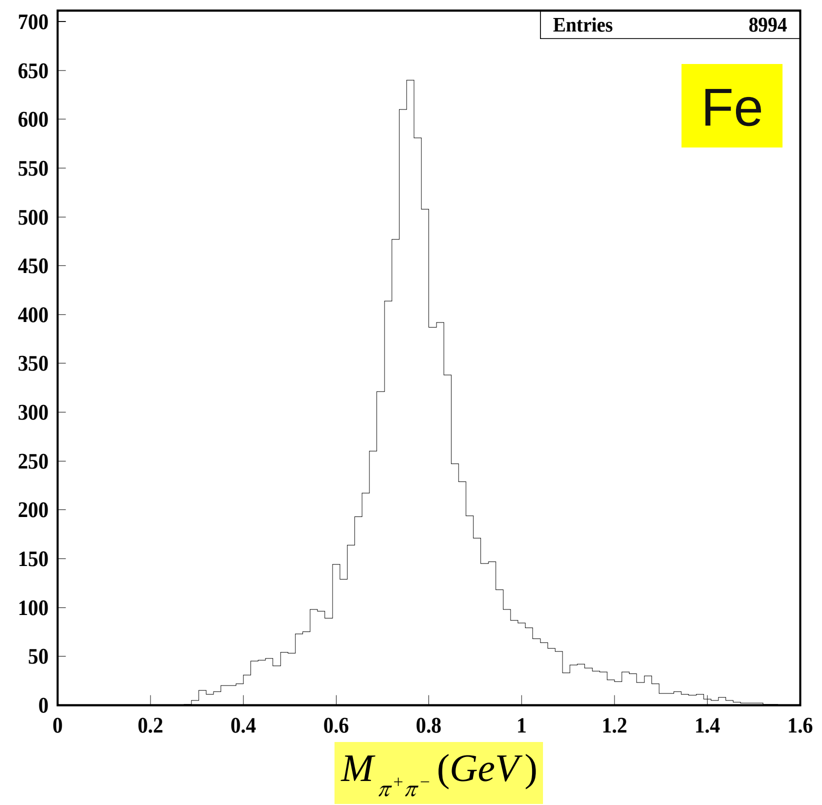
$\nu = E - E'$
$Q^2 = -(q^\mu)^2 \cong 4\, E\, E' \sin^2(\theta/2)$
$t = (q^\mu - \nu^\mu)2$
$W^2 = (p^\mu + q^\mu)^2 = -Q^2 + M_p^2 + 2M_p\nu$

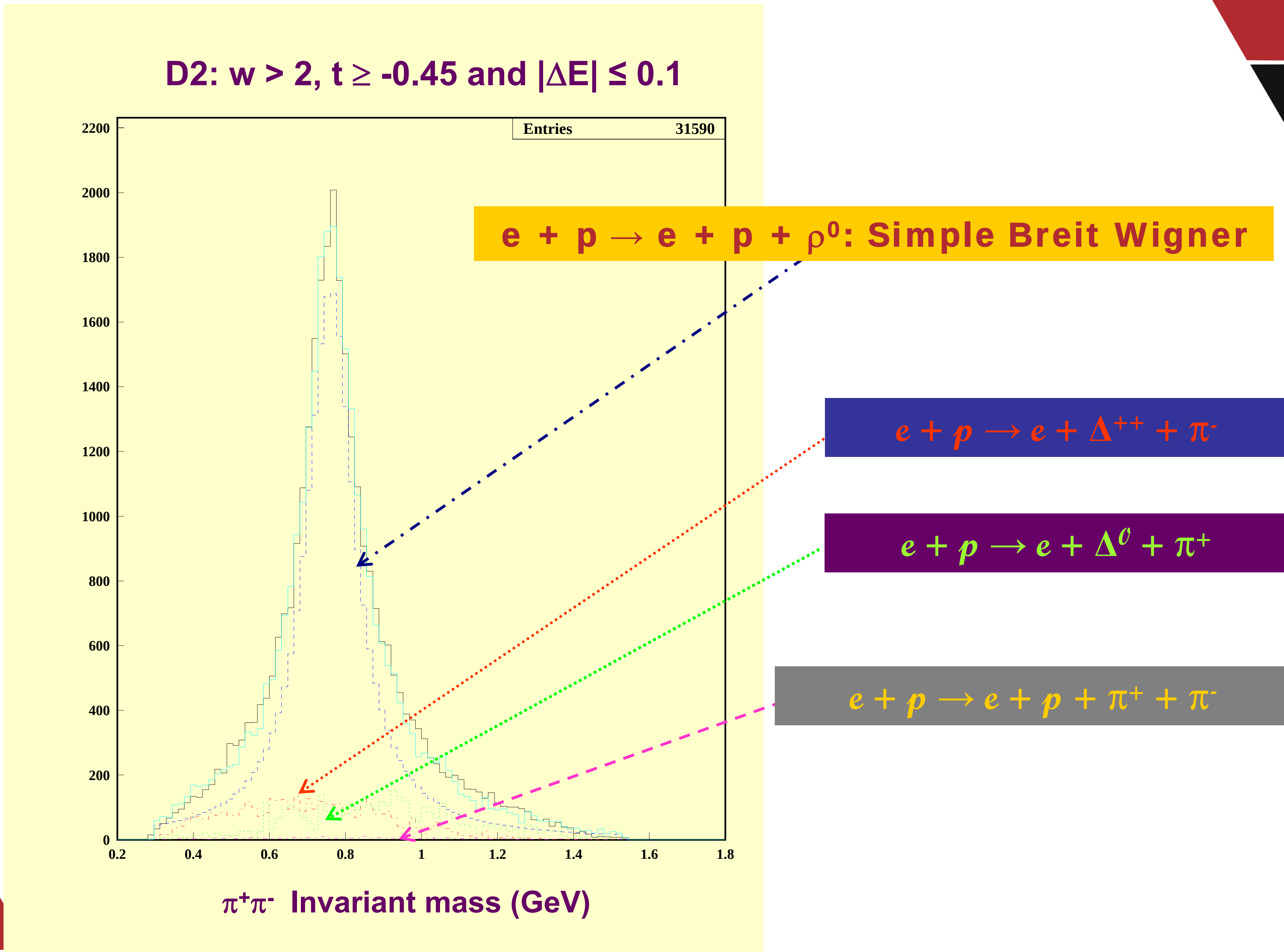
- **$W \geq 2$ GeV**
  $\Rightarrow$ avoid resonance region
- **$-t \leq 0.45$ GeV^2**
  $\Rightarrow$ select diffractive process
- **$|\Delta E| \leq 0.1$GeV**
  $\Rightarrow$ select exclusive channel
- **$\Delta E = \nu - E_\rho + t/2M_p$** is the missing energy from $\pi^+\pi^-$ pair due to the creation of any additional final state particles

Two pions invariant mass



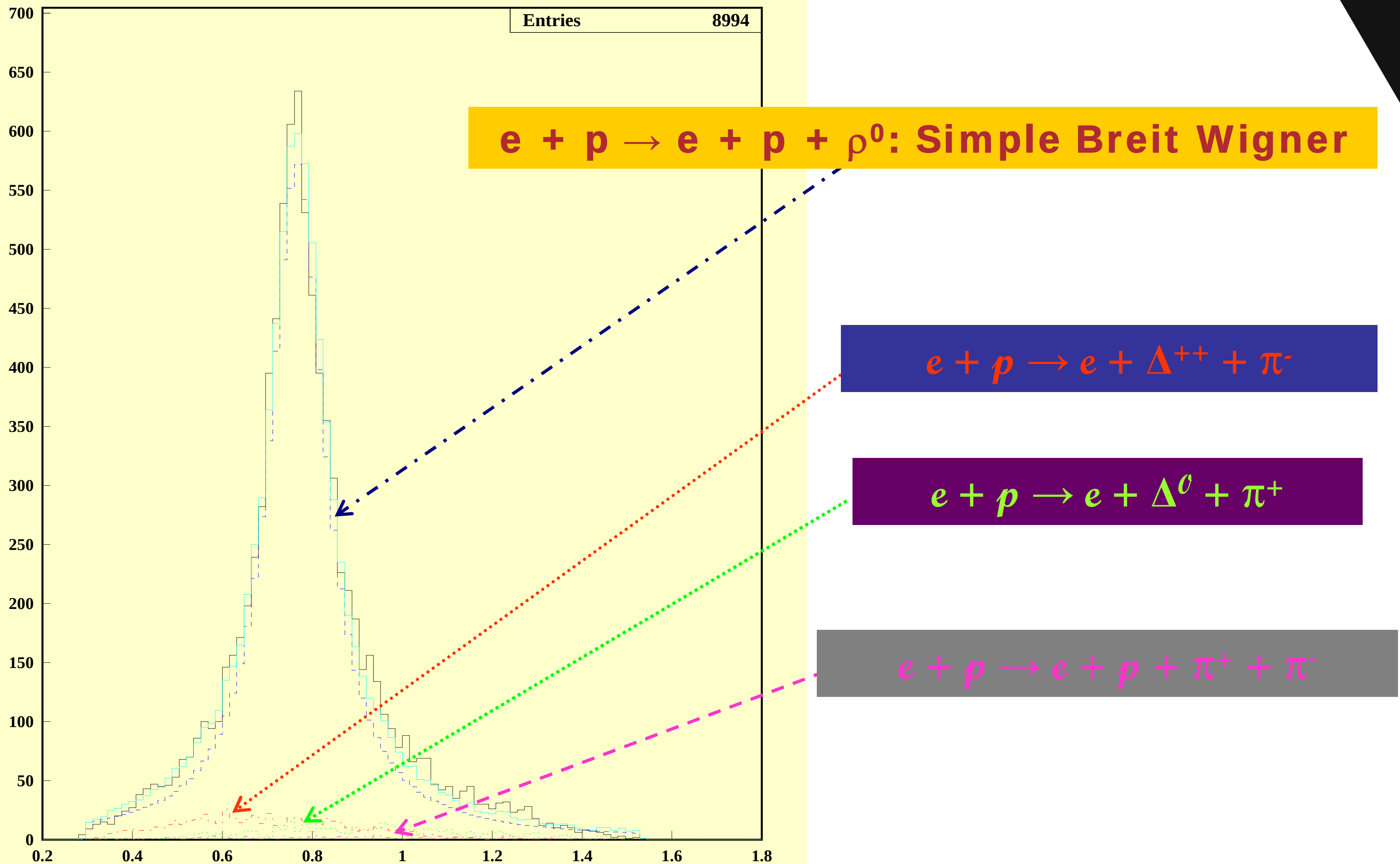
After w, t and ΔE cuts





D2: w > 2, t ≥ -0.45 and |ΔE| ≤ 0.1
Entries 31590
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
π+π- Invariant mass (GeV)
e + p → e + p + ρ0: Simple Breit Wigner
e + p → e + Δ++ + π-
e + p → e + Δ0 + π+
e + p → e + p + π+ + π-

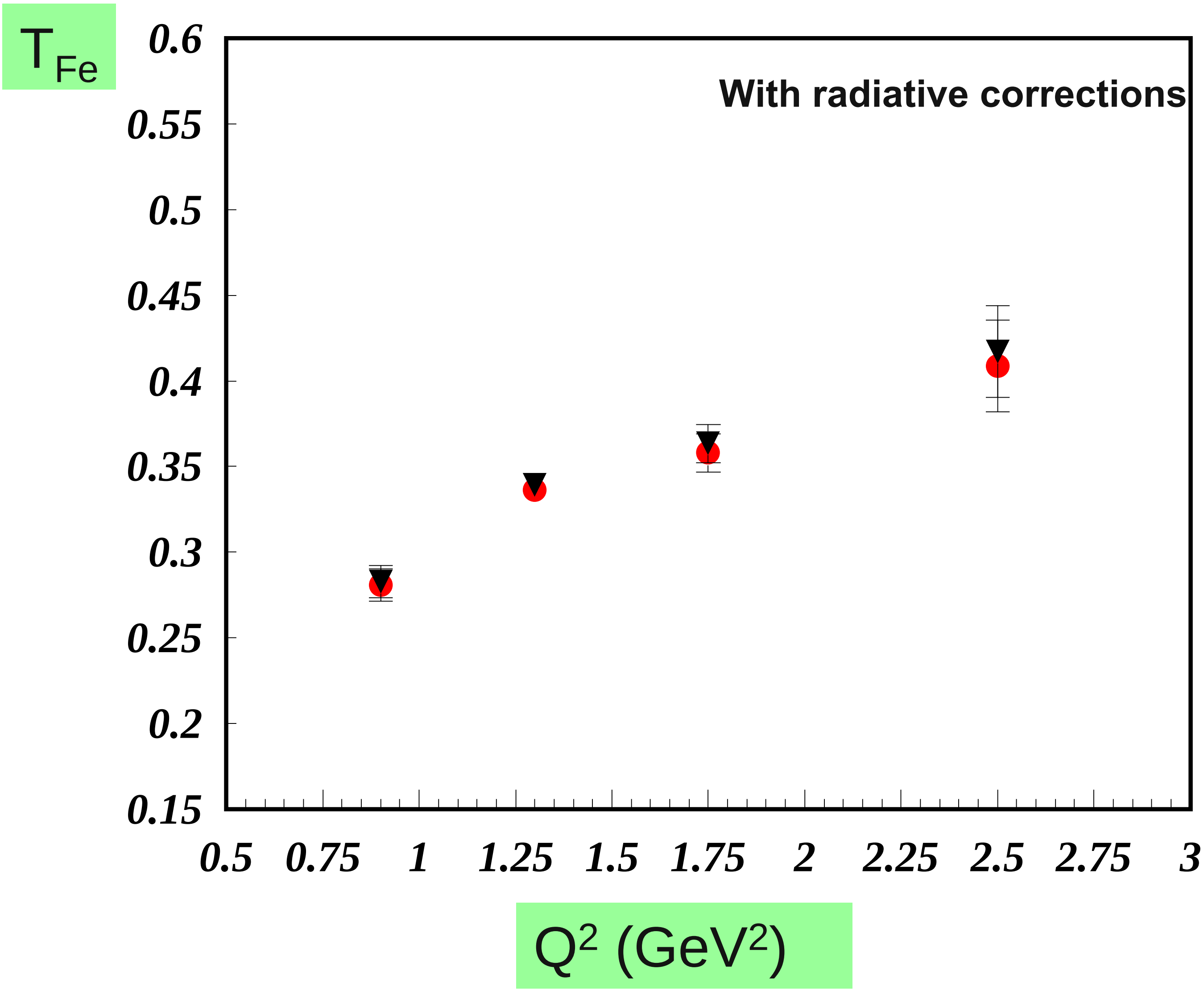
Fe: w > 2, t ≥ -0.45 and |ΔE| ≤ 0.1



$\pi^+\pi^-$ Invariant mass (GeV)

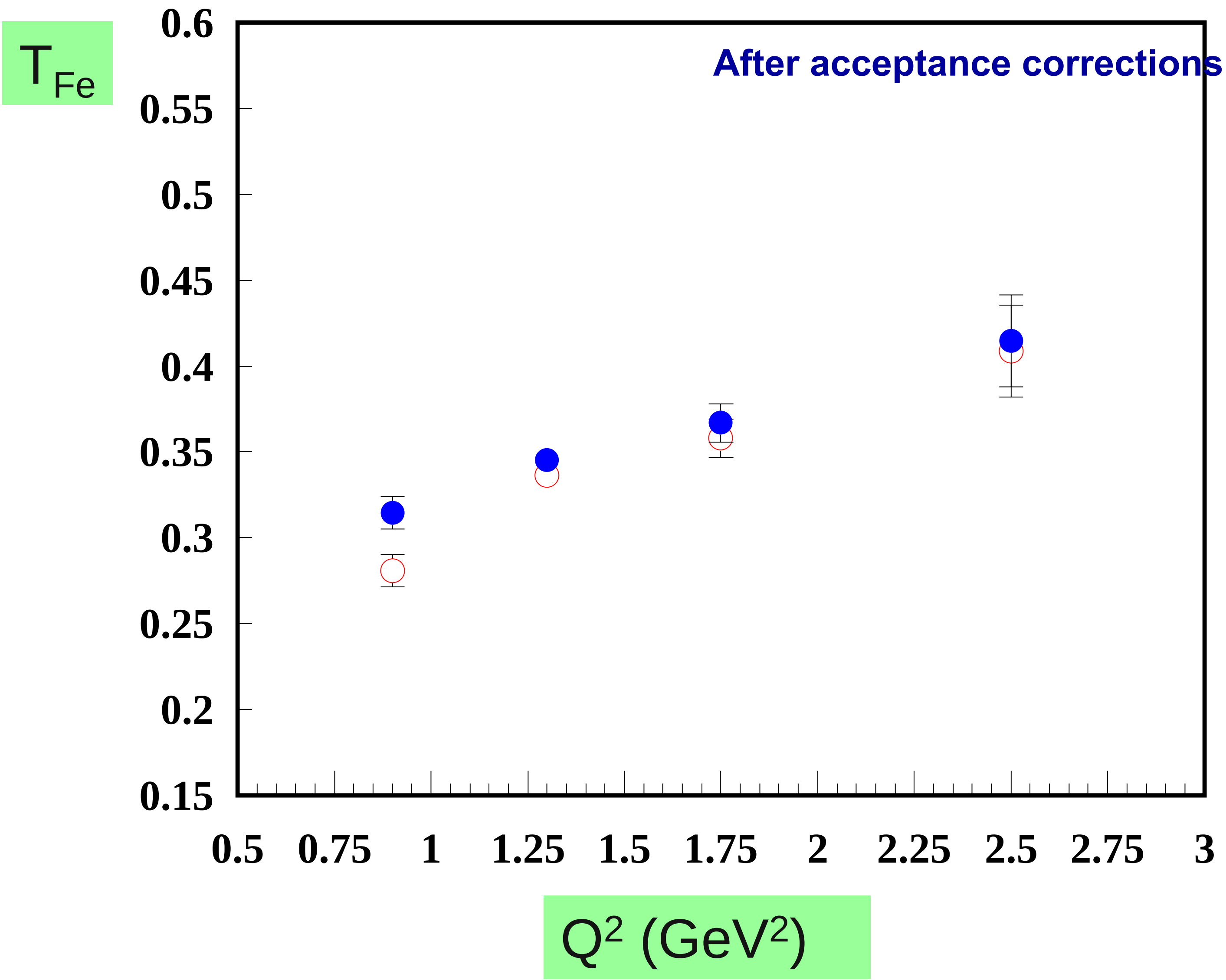
Radiative corrections

T_A vs Q^2 corrected with radiative effect



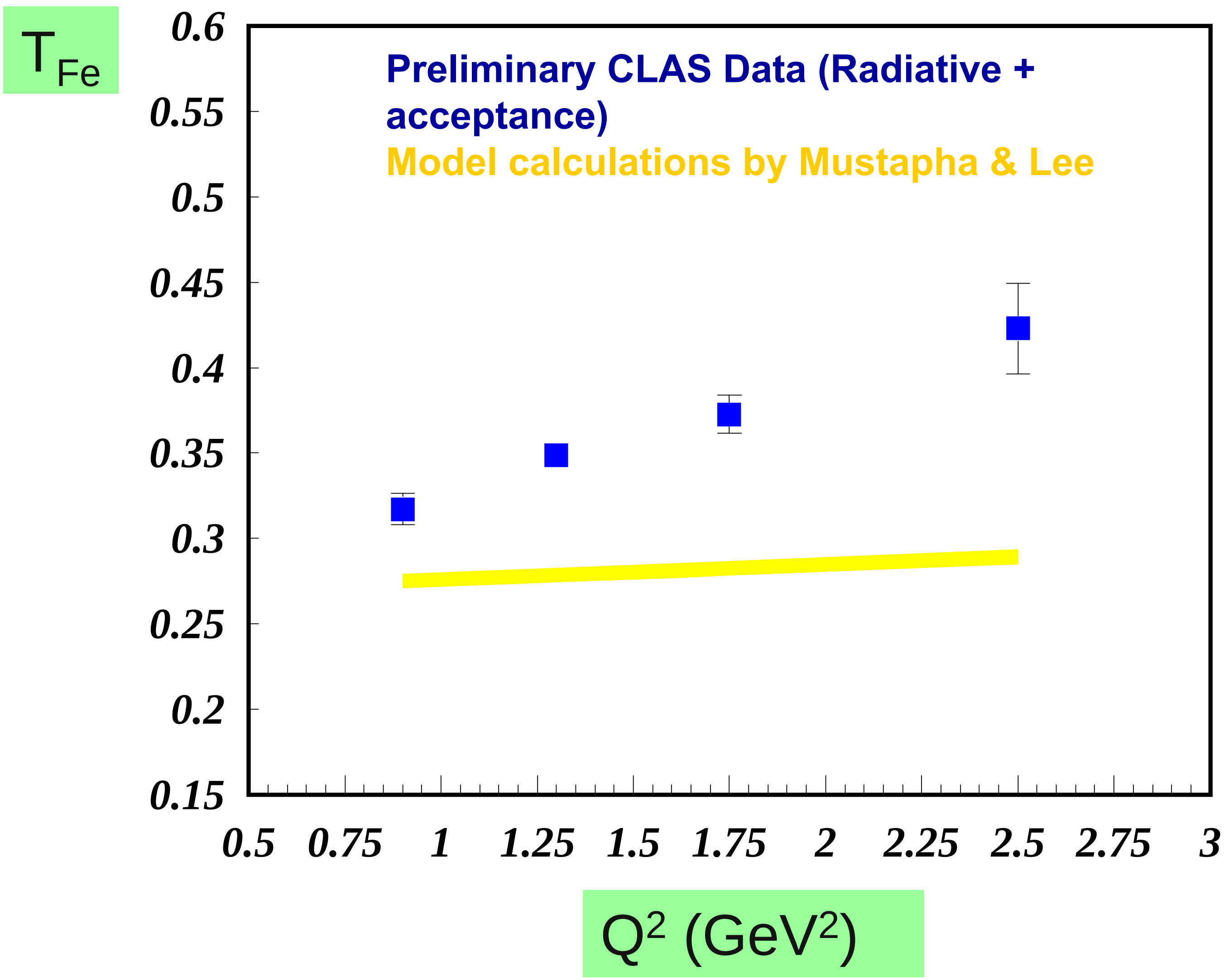
Acceptance correction

T_A vs. Q^2 corrected with acceptance effect

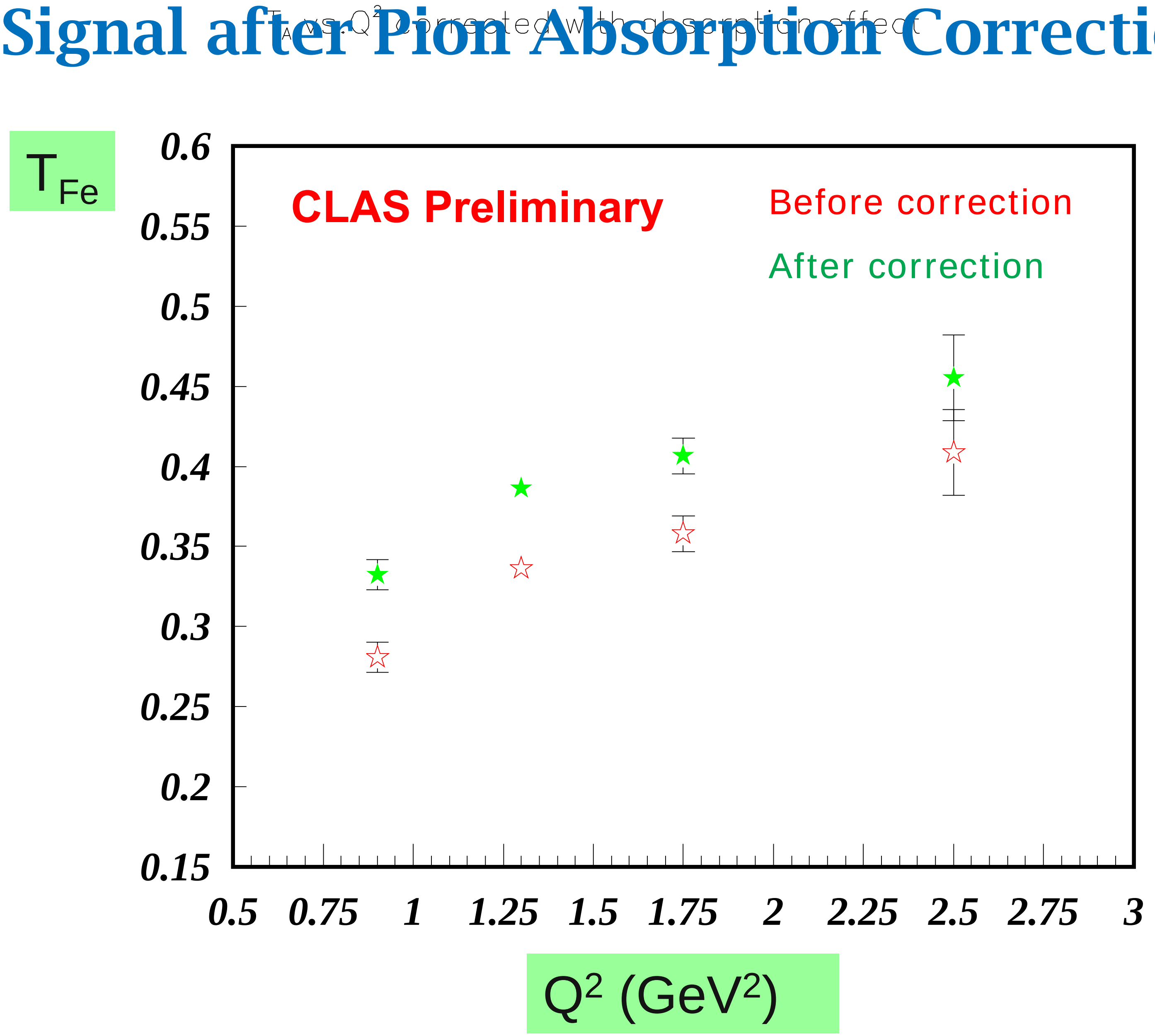


Pion absorption (Continued)

T_A vs. Q^2 corrected with acceptance and radiative effects



CT Signal after Pion Absorption Correction



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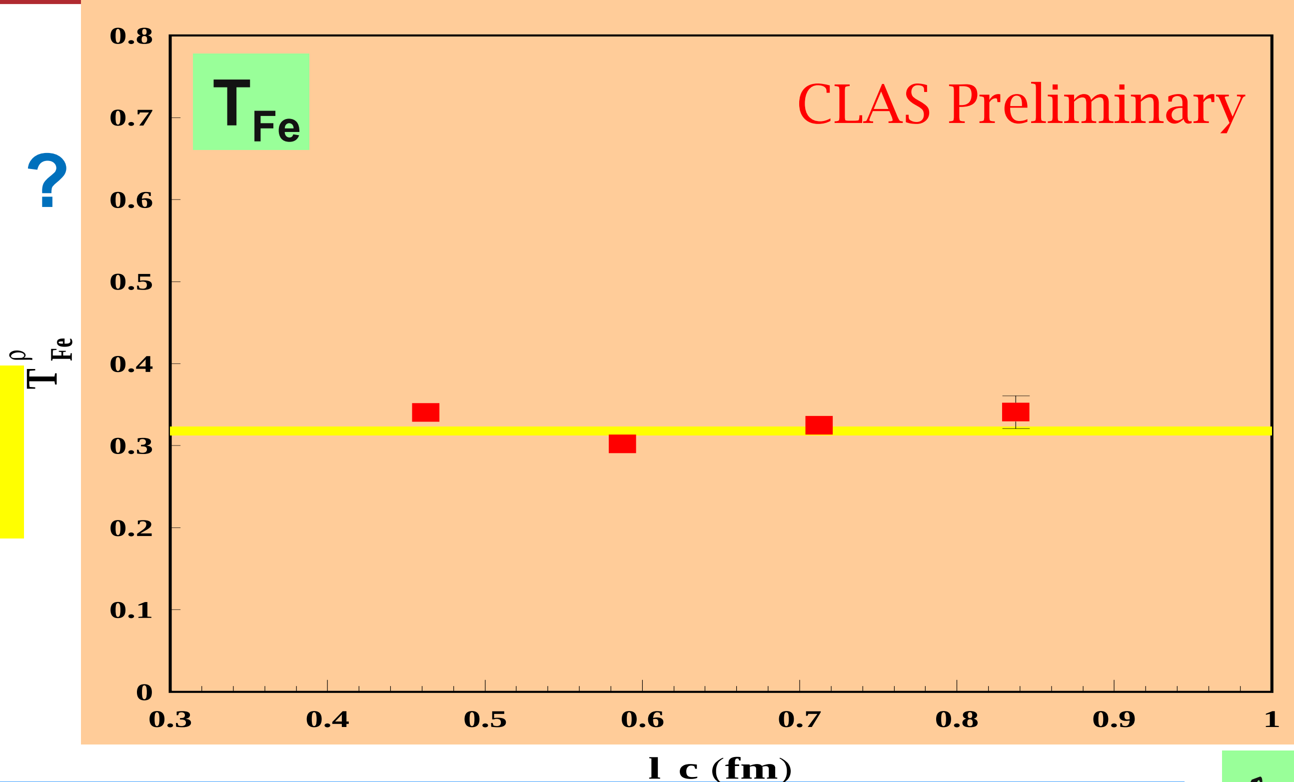
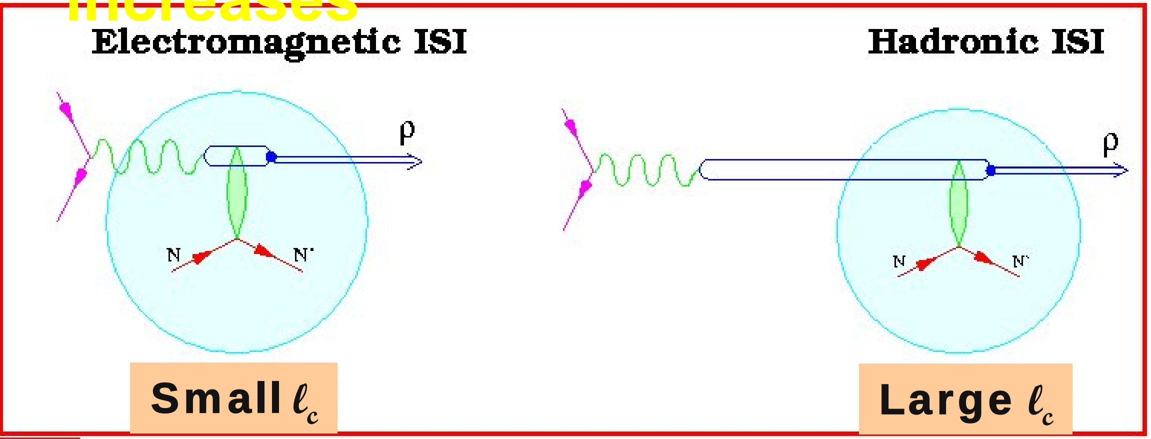


Coherence Length

$\ell_c = 2\nu/(M_V^2 + Q^2)$

ℓ_c

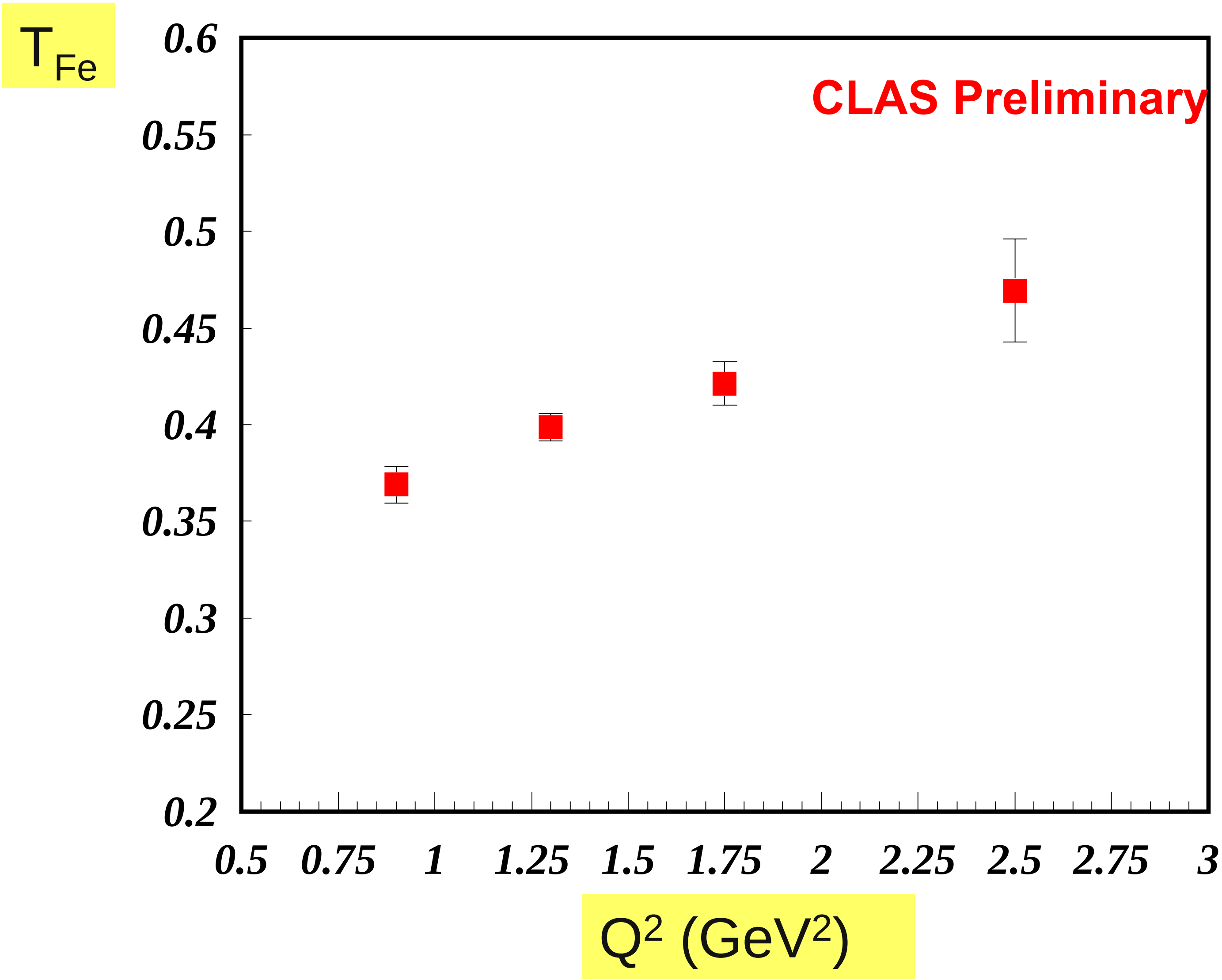
Coherence length effect (CL): Q^2 increases $\Rightarrow T_A$ increases



- Coherence Length effect can mimic CT signal
- To be safe, one should keep ℓ_c fixed and measures the Q^2 dependence of T_A

Preliminary Results from CLAS EG2 data

T_A.vs.Q^2 corrected with acceptance, radiative and absorption effects



Summary and Outlook

- Preliminary results from CLAS EG2 data show a strong Q^2 dependence of the nuclear transparency for Fe as predicted by the theory (B. Kopeliovich et al., Phys. Rev C 65 (2002) 035201)
- Results for 4 GeV iron and 5 GeV carbon are coming soon
- Work on systematic uncertainties is underway